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Travel Times of Water Derived from Three Naturally Occurring Cosmogenic Radioactive Isotopes

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Hydrological travel times are studied on scales that span six orders of magnitude, from daily event water in stream flow to pre-Holocene groundwater in wells. Groundwater vulnerability to contamination, groundwater surface water interactions and catchment response are often focused on “modern” water that recharged after the introduction of anthropogenic tritium in precipitation in 1953. Shorter residence times are expected in smaller catchments, resulting in immediate vulnerability to contamination.

We studied a small (4.6 km^2) alpine (1660-2117 m) catchment in a Mediterranean climate (8 ˚C, 1200 mm/yr) in the California Sierra Nevada to assess subsurface storage and investigate the response to the recent California drought. We analyzed a combination of three cosmogenic radioactive isotopes with half-lives varying from 87 days (sulfur-35), 2.6 years (sodium-22) to 12.3 years (tritium) in precipitation and stream samples.

Tritium samples (1 L) are analyzed by noble gas mass spectrometry after helium-3 accumulation. Samples for sulfur-35 and sodium-22 are collected by processing 20-1000 L of water through an anion and cation exchange column in-situ. Sulfur-35 is analyzed by liquid scintillation counting after chemical purification and precipitation. Sodium-22 is analyzed by gamma counting after eluting the cations into a 4L Marinelli beaker.

Monthly collected precipitation samples show variability of deposition rate for tritium and sulfur-35. Sodium-22 levels in cumulative yearly precipitation samples are consistent with recent studies in the US and Japan. The observed variability of deposition rates complicates direct estimation of stream water age fractions.

The level and variability of tritium in monthly stream samples indicate a mean residence time on the order of 10 years and only small contributions of younger water during high flow conditions. Estimates of subsurface storage are in agreement with estimates from geophysical studies. Detections of sodium-22 confirm a small fraction of younger ($<$ 5 years) water. Low concentrations of sulfur-35 suggest very small contributions of same-year snowmelt or precipitation. Results from two contrasting years (severe drought in 2015 and near-normal conditions in 2016) illustrate travel time responses to hydrological conditions and further characterize the catchment properties.

Combined analysis of three cosmogenic tracers provides a unique insight into the functioning of the catchment and constrains the volume of subsurface water storage. Short-lived naturally occurring radioactive isotopes sulfur-35 and sodium-22 are especially useful for vulnerability assessment of springs and karst systems where a contribution of very young water is expected.

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